How Multitasking Interacts with Visual Impairment and Age on Measures of Driving Performance

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This study investigates the impact of visual and auditory secondary tasks on the driving performance of participants (14 younger and 14 older) with simulated visual impairment. Participants drove around a closed road circuit under single- and dual-task conditions. Driving performance measures included road sign recognition, detection and avoidance of low-contrast hazards, gap judgment, and time to complete the course. Driving with two levels of visual impairment was compared against a baseline condition: goggles designed to replicate the effects of cataracts or blur (uncorrected refractive error visual impairment were used to simulate), and goggles were used to reduce binocular visual acuity to a mean level of 20/40. Secondary tasks required participants to add orally pairs of numbers presented through a computer speaker (auditorily) or via a dashboard-mounted monitor (visually). Results indicate that visual impairment significantly reduces driving performance ($P < 0.05$) and the differences are greatest under the cataract condition. Multitasking (e.g., talking on a cell phone or using in-vehicle navigational devices) further exacerbated these effects, and the visual dual task had a greater detrimental effect on driving performance than did the auditory dual task ($P < 0.05$), particularly for the older drivers. Overall, results indicate that multitasking impairs driving performance and the effects are exacerbated for older drivers and younger drivers with visual impairment. This finding has important implications as driving and in-vehicle environments become increasingly complex and older people comprise the fastest-growing segment of the driving population.

Older drivers have fatal crash rates that are comparable to or greater than those of younger drivers, and older drivers also are considered to be at fault in 80% of all crashes. The underlying reasons for this disproportionate involvement of older individuals in crashes have not been well established; however, it is recognized that the effects of age alone cannot account for many of these crashes. This has led to an increased interest in examining the performance of drivers with sensory impairments that become more prevalent with age. Impairment of visual function is of particular interest and has been cited as a likely contributing factor to the increased crash rates of older drivers (*1*). Although less evidence is related to the effects of auditory impairment on driving, hearing impairment has been implicated as a risk factor for vehicle crashes (*2*).

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The driving situation and the in-vehicle environment are becoming increasingly complex; hence the problems of the older driver are likely to increase. Some vehicles are equipped with sophisticated navigation and entertainment systems, which like cell phones add to the driver's attentional burden by distracting them from their primary task. Some of these navigation systems are specifically marketed as safety-enhancing features for older drivers, yet their potential to improve safety has not been demonstrated.

Intrinsic factors likely to affect older drivers' performance include vision and cognition. The contribution of impaired vision to the driving difficulties of the elderly is evidenced by a range of studies. Crash risk is increased in older drivers with cataracts (*3*) and glaucoma (*4*) and in those drivers with impairments in selected visual functions, including visual field, dynamic visual acuity, contrast sensitivity, and visual attention (*5*). Results of studies using a closed road circuit have indicated that simulated vision impairment (specifically cataracts); visual field restriction (*6–8*); and true vision impairment (including cataracts, glaucoma, and age-related maculopathy (*9*, *10*)) significantly impair driving performance. Impaired vision makes the detection of and reaction to formal and informal road cues difficult and exacerbates existing deterioration in physical ability and judgment. The problems of vision impairment also are likely to increase as driving and in-vehicle environments become more complex and drivers are required to divide their attention across multiple tasks.

More specifically, for the vision impaired, the ability to perform concurrent tasks may be compromised because the processing, interpretation, or both of visual input may represent a significant attention-demanding task in itself. Recent evidence suggests that this may be the case. Turano et al. report that individuals with vision impairment have greater difficulty walking in unfamiliar places; they expend more mental effort and walk more slowly than those with normal vision (*11*). The walking deficits observed in visually impaired individuals were even worse than in controls when participants were required to undertake a secondary auditory task. The implications of these findings for driving performance are yet to be investigated.

Older drivers also are more likely to experience declines in cognitive function that may increase crash risk, especially under dual-task conditions. For instance, although older adults experience small declines in some cognitive abilities (e.g., short-term memory span and recognition memory), age-related changes are greater for tasks that require prospective memory (i.e., reminding themselves to perform a task in the future), executive function, and working memory (*12*). These latter tasks usually require participants to maintain or manipulate information in working memory while performing another task concurrently. Recent studies document a link between tests of cognitive function and driving performance measures (*13*). Studies also have begun to identify how loads on cognitive processes, including working memory, affect the efficiency of visual search that may be important for detecting potential road hazards (*14*).

The Wickens multiple-resource model predicts a greater interference between tasks that compete for the same perceptual modality (visual or auditory), associated working memory subsystems (visual–spatial sketchpad or phonological loop), or mode of response (manual or vocal) (*15*). Thus, a secondary auditory task is predicted to interfere less with the manual control task of driving because it relies on a distinct set of resources associated with verbal perception, verbal working memory, and generation of a vocal response. However, the addition of a secondary visual task necessitates sharing resources with visual perception and spatial working memory. Processing a degraded visual image may place significant demands on this finite pool, thereby reducing any excess capacity that would be allocated to another visual task.

In addition to having these central (i.e., cognitive) effects on performance, a secondary visual task also may interfere at a more peripheral level. The visual presentation of information creates a competing visual channel that must be monitored by shifting gaze from outside to inside the vehicle. A gaze shift could potentially result in poorer hazard and sign detection and loss of vehicle control. Results of driving simulator studies have indicated that when drivers are engaged in a secondary task, they miss more traffic signs and respond more slowly (*16*) and are less likely to detect changes in driving scenes (*17*). These results could reflect top–down influences on the strategic allocation of attention. For instance, drivers might respond to increased load by attending more to the driving scene directly in front rather than monitoring peripheral visual stimuli (e.g., pedestrians) of lower priority. Alternatively, a dual task may divert attention from the driving scene to a cell phone conversation.

The overall aim of this study was to investigate the effects of visual impairment, age, and multitasking on real-world measures of driving performance and to develop a preliminary understanding of the interactions among these factors.

METHODS

The effects of multitasking on measures of the driving performance (including the detection and recognition of road signs and large low-contrast hazards, judgment of gaps between cones, and time to complete the course) were observed as younger and older participants drove around a closed road driving course under two levels of simulated visual impairment.

Participants

The study participants were 14 young (mean age = 27.3 ± 5.3 years, range: 19 to 34 years) and 14 elderly (mean age = 69.2 ± 4.9 years, range: 63 to 77 years) drivers who had normal corrected vision, were free of ocular pathology, and were in good general health. Participants were screened for cognitive, visual, and auditory impairment before the experiment. All participants scored 24 or more on the Mini-Mental State Examination (MMSE) (*18*), had visual acuity within normal limits for their age [as measured with a logarithm of the minimum angle of resolution (logMAR) chart], and had normal hearing sensitivity for their age (as defined by pure tone thresholds lower than or equal to 20 dB hearing loss at octave frequencies between 500 and 4,000 Hz).

To obtain a general sense of each participant's driving experience and habits, a confidential questionnaire was administered. Only findings relevant to general driving characteristics are reported here. The older participants reported 40 to 56 years of driving experience ($M = 46.2$ years), whereas younger participants reported 3 to 15 years of driving experience ($M = 8.0$ years); all reported that they drove regularly (78.5% of both groups reported that they drove four to six times per week or every day).

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee. All participants were given a full explanation of the experimental procedures, and written informed consent was obtained; they had the option to withdraw from the study at any time.

Driving Assessment

Driving performance was assessed under daytime conditions on a 5.1-km closed road circuit that was free of other vehicles and representative of rural roads (*7*). The vehicle was a right-hand–drive sedan with automatic transmission and power steering. Participants were given a practice run to familiarize themselves with the car, the road circuit, and the driving tasks. The practice run was performed in the direction opposite from that of the test run to minimize any familiarity effects. For the main test circuit, participants were instructed that they would be required to perform numerous concurrent tasks while driving at what they felt was a safe speed, to drive in their own lane except when avoiding hazards, and to obey all regulatory signs. Performance measures consisted of the time to complete the road course, number of road signs recognized, the number of road hazards recognized, the number of road hazards hit, correct gap judgments, and correct responses on the secondary tasks.

Driving performance was assessed under two visual impairment conditions compared with a baseline condition. Visual impairment was simulated using two sets of goggles: one designed to replicate the effects of cataracts [described previously by Wood and Troutbeck (*7*)] and the other designed to replicate blurred vision. The goggles used to simulate the effects of cataracts reduced distance visual acuity to a mean level of 20/40, and their use is referred to as the cataract condition. In the goggles used to simulate blurred vision, binocular plus lens blur reduced the distance visual acuity of each participant individually to that of the cataract-simulating goggles; the use of these goggles is referred to as the blur condition. All visual degradation conditions (cataract simulation and blurred vision) were incorporated into full-aperture lenses and mounted in the goggles with each participant's distance refractive correction used for driving, thereby permitting a wide field of view.

The secondary task required the participants to verbally report the sums of number pairs presented through a computer speaker (auditorily) or a dashboard-mounted monitor just to the left of the steering wheel (visually) while driving. The visual task consisted of the simultaneous presentation of pairs of large single-digit numbers subtending between 3.5 and 4.8° of visual angle, well above the visual threshold of all participants for all the viewing conditions included in this study. Auditory stimuli were presented at a comfortable listening level set by each participant. Number pairs were presented approximately every 3.5 s.

Each participant thereby drove the track nine times (three visual conditions times three distraction conditions). The order of runs around the driving circuit was randomized, and the runs were conducted over two visits to the test track separated by at least 1 week to minimize learning effects.

A composite driving score—derived to capture the overall driving performance of the individual participants compared with the whole group—included road sign recognition, cone gap perception, course time, and number of hazards hit. This last measure was selected rather than including both road hazards seen and road hazards hit, because they are highly correlated. The Z scores for each of these four driving measures were determined and the mean Z score for each participant was calculated to provide a composite score (data were transformed where necessary to ensure that better performance was always represented by a more positive Z score). Equal weighting was assigned for all tasks. Even though some driving tasks may be more important to road safety than others, in the absence of strong evidence to support differential weighting and as a first step to derive a composite index of driving performance, it was determined that equal weighting would be the most suitable approach.

RESULTS

The group mean data for the composite driving Z score demonstrate the performance differences of the participants as a function of visual status (normal, blurred, or simulated cataracts), whether they were required to complete a secondary task (visual or auditory) while driving, and age group (Figure 1).

An analysis of variance (ANOVA) with two within-subject factors (driving task and visual status) and one between-subjects factor (driver age) demonstrated that the main effects of driving task [$F(2,52) = 6.726$, $P = 0.003$] and visual status [$F(2,52) = 62.07$, $P < 0.001$] were both significant. The main effect of driver age also was significant, and indicated that older drivers had poorer driving performance than younger drivers overall [$F(2,26) = 11.76$, $P < 0.001$]. Interactions between vision and group [$F(4,52) = 4.45$, $P = 0.004$] and task and vision [$F(4,104) = 3.85$, $P = 0.006$] were significant. Model-based contrast analysis indicated that driving performance was significantly better ($P < 0.05$) for the single-task condition compared with either the dual-visual or dual-auditory secondary task condition (but these were not significantly different from each other). Driving performance scores were all significantly different from one another under the three visual conditions ($P < 0.05$), where performance was most compromised when driving under the cataract condition. The interaction effects indicated that the detriment to driving performance was greater for the older drivers under cataract conditions and for all drivers under the cataract condition when undertaking the secondary visual task.

Group mean data for performance on the secondary summing task are given as a function of how the summing task was presented (visually or auditorily), the visual status of the driver (normal, blurred, or simulated cataracts), and driver age (Figure 2). An ANOVA with two within-subject factors (driving task and visual status) and one between-subjects factor (driver age) demonstrated a significant main effect for visual status [$F(2,50) = 17.09$, $P < 0.001$] and significant interactions between task and vision [$F(2,50) = 11.69$, $P < 0.001$] and task, vision and group [$F(2,50) = 4.72$, $P = 0.013$], where participants made significantly more errors on the visual dual task when driving under cataract conditions and these effects were exacerbated for the older drivers.

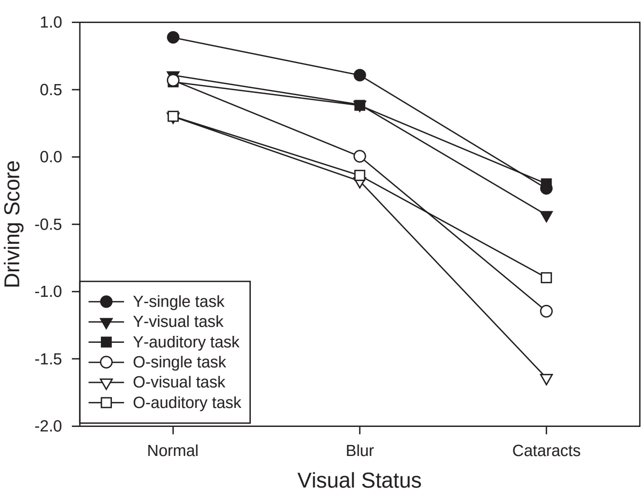

FIGURE 1 Group mean composite driving score as function of visual status, task, and driver age (Y = younger participants, O = older participants).

DISCUSSION

The results demonstrate that driving performance was worse when participants drove with simulated visual impairment under the dual-task condition than under the single-task condition and that there was an interaction between the two. Age-related differences also were observed in the composite driving score, whereby older drivers performed worse than younger drivers.

The visual status of drivers had a significant effect on driving performance: the simulated cataract condition most degraded driving performance, even though the visual acuity under the cataracts condition was equal to that of the blur condition. The results for simulated cataracts are in agreement with previous findings that suggest that cataracts have a detrimental effect on indices of driving performance (*3, 7, 8*) and that these effects are greater for older people (*8*).

The results that compare the impact on driving performance under blur and cataract conditions indicate that driving performance is not well predicted by standard measures of visual acuity, because it was equal under these two conditions. The reduction in contrast sensitivity resulting from the cataract simulation probably had a greater impact on driving performance, and this hypothesis is supported by the results of related studies of simulated cataracts (*8*) and of drivers with true cataracts (*19*); in both cases, contrast sensitivity deficit was the best predictor of impaired driver safety.

The overall driving performance of all participants was worse under dual-task conditions than under single-task conditions, and this finding is in agreement with previous driving simulator studies. Richards et al. report using a laboratory-based image-flicker task to determine that response times to search for change in images of driving scenes were significantly slower in the presence of a concurrent auditory task (*20*). In addition, results of simulator-based studies have indicated that driving performance is affected when participants must respond to a secondary task (*16*). The secondary task appears to interfere, affecting the detection of hazards and changes in the driving scene (*21*).

Dual tasking also has been shown to be a problem in the driving situation, as evidenced by findings indicating that cell phone use

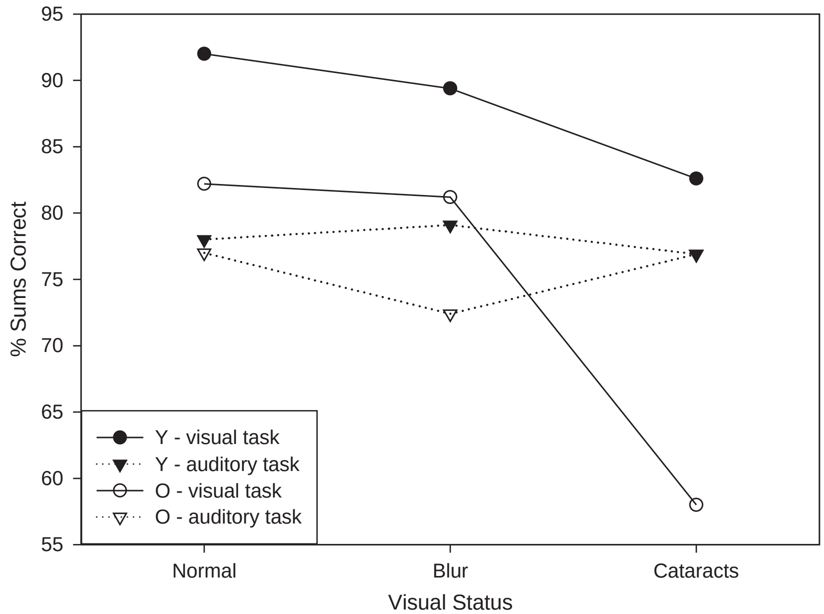

FIGURE 2 Group mean correct performance on the secondary task as function of visual status, task, and driver age (Y = younger participants, O = older participants).

increases crash risk by more than fourfold (*22*). Interestingly, no interaction was found between driver age and task except when participants were driving under the cataract condition, when older drivers were most affected. The results of recent studies on driving simulators have indicated that the effects of the secondary tasks are not significantly affected by driver age (*23*), as found in the real-world study reported in this paper.

The finding that the older drivers were more affected than younger drivers by the cataract condition is interesting. In this study, the simulated cataracts made identifying the road edge difficult and thereby increased the attention required for drivers to ensure that they stayed on the roadway. This may explain why the visual dual task interfered more with driving under the cataract condition for the older drivers, given their reduced attentional capacity compared with younger drivers (*24*).

The results also demonstrate that the effects of the secondary visual and auditory tasks on driving performance were similar, except when the participants were driving under the cataract condition. These results are not consistent with predictions derived from theories of divided attention (*25*), which suggest that a visual task will interfere with driving more than an auditory task, because the visual task competes for the same attentional reserves as those used when driving. However, the findings are consistent with data that suggest that cell phone conversations may interfere with the attention-capturing properties of stimuli in the driving environment (*26*). Participants reported feeling uncomfortable when they took their eyes off the road to look at the visual display, especially under the cataract condition. Secondary task performance also was worse for the visual dual task of driving under the cataract condition, and these effects were exacerbated for the older drivers.

In summary, both younger and older drivers were affected by the secondary task, such that dual-task performance (with visual or auditory stimuli) was worse than single-task performance for both age groups. Simulated cataracts caused the greatest decrement in performance under visual dual-task conditions, particularly for older drivers.

Even though visual acuity was matched for the blur and cataract conditions, the impact of impairment on driving performance from simulated cataracts far exceeded that of blurred vision, indicating that visual acuity is a poor predictor of the detrimental effects of cataracts on driving performance. The driving performance of the older drivers also was significantly worse than that of the younger participants, in accord with previous studies that have reported that the crash rates of older drivers are higher per distance traveled than those of their younger counterparts (*27*).

The findings from this study provide an important basis for future investigations to (*a*) determine the effects of interactions among driver age, visual status, and types of dual tasks on performance and (*b*) develop a better understanding of the effects of commonly occurring visual impairments such as cataracts on driving behavior and the acquisition of driving-related information. Including two additional control groups into the experimental design—no-cognitive visual and no-cognitive auditory control conditions (e.g., the simple presentation of luminance transients or sounds)—would more clearly separate the visual and cognitive factors and thereby allow the determination of which factor has the greater impact on the relationships described.

One might predict that the effect of the cataract condition might be reduced with a simple auditory or visual detection task; indeed, previous work documents that simple cognitive and perceptual tasks produce little dual-task interference (*28, 29*). Although the use of simulated visual impairment allows the filtering of vision effects alone without introducing variations in cognition, experience, or personality type, it is recognized that the effects observed in this study may be greater than for people with true vision impairment, who have had time to become accustomed to their degraded vision and develop compensatory behaviors. Future studies are planned that further investigate the impact of multitasking for drivers with a range of true visual impairments.

Another consideration is examining the impact of vision and hearing impairment and multitasking on driving, given that hearing impairment—like vision impairment—is highly prevalent in older people; recent Australian studies report that approximately 60% of community-based people older than 60 years of age have such an impairment (*30*). Gallo et al. (*31*) report an association between hearing impairment and reports of adverse driving events, and Ivers et al. (*2*) find that higher crash rates are associated with poorer visual acuity and self-reported hearing loss, especially in the right ear. Similarly, driving cessation has been linked with hearing and vision impairment (*32*). However, much research to date has relied on self-reported driving performance, which may have poor content validity. In addition, some older drivers experience dual sensory loss (i.e., both hearing and vision impairment); the combined impact on driving performance is unknown and will be the subject of future research.

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